

Introduction: The OSIRIS-REx (Origins Spectral Interpretation Resource Identification Security Regolith Explorer) Mission is a planetary science mission to study, and return a sample from, the carbonaceous asteroid 1999 RQ₃₆. The third mission selected under NASA's New Frontiers Program, it is scheduled to be launched in 2016. It is led by PI Dante Lauretta at the University of Arizona and managed by NASA's Goddard Space Flight Center. The spacecraft and the asteroid sampling mechanism, TAGSAM (Touch-And-Go Sample Acquisition Mechanism) will be provided by Lockheed Martin Space Systems. Instrumentation for studying the asteroid include: OCAMS (the OSIRIS-REx Camera Suite), OLA (the OSIRIS-REx Laser Altimeter, a scanning LIDAR), OTES (The OSIRIS-REx Thermal Emission Spectrometer, a 4-50 μm point spectrometer) and OVIRS (the OSIRIS-REx Visible and IR Spectrometer, a 0.4 to 4.3 μm point spectrometer). The payload also includes REXIS (the Regolith X-ray Imaging Spectrometer) a student provided experiment. This paper presents a description of the OVIRS instrument.

OVIRS Overview: OVIRS is a point spectrometer with a 4-mrad field of view (FOV) that provides spectra over the wavelength range of 0.4 – 4.3 μm . It employs wedged filters (also called a linear variable filters) to provide the spectrum. A wedged filter is a two-dimensional spectral filter in which the wavelength of transmitted light varies in a well defined fashion with position along one of the spatial dimensions. Spectra are measured with resolving power $R (= \lambda/\Delta\lambda)$ of 125 in the 0.4 to 0.9 μm spectral band ($\Delta\lambda < 7.5$ nm); with $R = 150$ in the 0.9 to 1.9 μm spectral band ($\Delta\lambda < 13$ nm); and with $R = 200$ in the 1.9 to 4.3 μm spectral band ($\Delta\lambda < 22$ nm). In addition, the spectral range from 2.9 to 3.6 μm is measured with $R = 350$ ($\Delta\lambda < 10$ nm, $\Delta\nu < 10$ cm^{-1}) to resolve key organic spectral features, such as those that have recently been observed on the asteroid 24 Themis ([1], [2]). These spectral ranges and resolving powers are sufficient to provide surface maps of mineralogical and molecular components including carbonates, silicates, sulfates, oxides, adsorbed water and a wide range of organic species. The OVIRS operates in a scanning mode, in which the rotational motion of the asteroid is combined with a rotation of the spacecraft about the OVIRS scan axis to sample a region of interest. In the expected operational scenario, OVIRS will provide full-disk asteroid spectral data, global spectral maps (20-m resolution), and

spectra of the sample site (0.08 – 2-m resolution). The instrument provides at least two spectral samples per spectral resolution element (spectral double sampling) taking full advantage of the spectral resolution. OVIRS complements the OTES instrument; combined these instruments produce unprecedented spectral coverage of the asteroid surface. OVIRS spectra will be used to identify volatile- and organic-rich regions. These data will be used in concert with data from all the other instruments to guide sample-site selection.

OVIRS Design:

Optics. OVIRS uses an off-axis parabolic (OAP) mirror to image the surface of the asteroid onto a field stop. The field stop selects a 4-milliradian angular region of the image. The light from this 4-milliradian area passes to a second OAP that re-collimates it and illuminates the Focal Plane Assembly. Because the beam speed is low ($\sim f/50$) this assembly, consisting of the array with the filter mounted in close proximity to it, is effectively at a pupil. Each detector element of the array “sees” the same spatial region of the asteroid but, as described below, different columns of the array “see” it at different wavelengths. The complete spectrum of the 4-milliradian spot is obtained in a single measurement. This is somewhat different than the case for some wedged filter spectral imagers, where the spectrum of a given point is built up over several frames (see, e.g. reference [3]). Because the spectral pitch and spectral resolution of the filter may be optimized to match the science requirements in different spectral regions, this design is very flexible. It also permits great instrument simplification—it eliminates a dispersive element and the extensive fore-optics of a slit-type spectrometer or the scanning mechanism required with a Fourier transform spectrometer.

Focal Plane Assembly. OVIRS uses a 510 x 512 pixel region of a 1024 x 1024 - H1RG HgCdTe detector array. H1RG arrays are constructed by hybridizing (via Indium bump bonds) a photosensitive HgCdTe detector layer, with the appropriate Hg/Cd ratio, to a CMOS Read Out Integrated Circuit (ROIC). OVIRS will use the array packaging configuration developed for the OCO mission and the 4.2 μm -cutoff photosensitive wafer flying on the WISE mission. A cutoff of 4.2 μm means that the sensitivity at 4.2 μm is 50% of the maximum sensitivity. The sensitivity falls roughly linearly from near maximum at 4 μm to near 0 at ~ 4.4 μm , allowing the 4.2- μm cutoff array to be used for spectral measurements at 4.3 μm . As is now standard practice, the array substrate will be removed, allowing photon sensitivity over the entire 0.4 to 4.3- μm region. The

substrate removal also reduces the effect of spurious signals from cosmic rays.

The filter consists of five 102 pixel x 512 pixel wedged filter segments bound together in a single assembly that is mounted within 1 mm of the surface of the 2-D detector array. The wavelength of transmitted light varies in the 512 pixel row dimension. Because the wedged filter segments are near the photo-active surface of the array, they effectively make each 102 pixel column of the array under a given segment responsive only to a narrow wavelength band. Each column corresponds to a single spectral element, and a full spectrum is created using data from all the columns. Pixels within a column will be summed to increase the signal-to-noise ratio. Because the wavelength may vary somewhat along a column due to spectral "smile" in the filter, only those pixels in each column whose central wavelength lies within the appropriate spectral range will be summed. The central wavelength of each pixel will be determined during ground calibration. The spectral resolution of the OVIRS filters is well within the state-of-the-art. For example, LEISA on New Horizons employed filters of resolving power 240 from 1.25 to 2.5 μm and 560 from 2.1 to 2.25 μm [3].

Electronics. Two electronics boards (the LVPS and C&DH boards) provide filtered power, control the temperature sensors, provide the command and high-speed data interface and housekeeping telemetry, and control the onboard calibrator. A third board contains the SIDECAR (System for Image Digitization, Enhancement, Control and Retrieval) ASIC which controls all array functions, including A/D conversion, bias and signal amplification, and detector clocking. OVIRS shall use double correlated sampling to reduce system noise. All functions required to operate OVIRS are supplied by these 3 boards and all three boards are functionally redundant.

In order to obtain the high SNR required for OVIRS, at least 30 pixels will be averaged in each column. This conservative number, used in sensitivity modeling, is based on worst-case estimates of both spectral "smile" and scattering at segment boundaries. The actual number of pixels summed will be determined in instrument testing. The data will first be filtered using a pre-measured bad pixel map. To prevent cosmic ray events from contaminating the spectra while still reducing the data volume, pixels will be averaged in subsets before transmission to the ground. Contaminated subsets will be removed in ground processing before summing the remaining subsets at each wavelength to obtain the final spectrum.

Thermal Design. The detector array is thermally coupled to a two-stage passive radiator to obtain focal plane temperatures of ~ 105 K. This reduces the dark current sufficiently that dark current noise is never the

dominant noise source with more than a factor of two margin. The camera enclosure shields its contents from radiation and contaminants and mounts to the OSIRIS science deck. A cold baffle in the optical path limits the thermal background signal from the instrument enclosure. In addition, small radiators will reduce the temperature of the optics enclosure itself to less than 160 K, further reducing thermal background noise. The thermal design is such that, except for very low asteroid surface temperatures and very low solar reflectance, the measurement noise is dominated by source photon noise. For very low asteroid signal, the primary noise term is the low read noise. This is the optimum design from a noise standpoint.

Test, Qualification, and Calibration Requirements: OVIRS will be calibrated prior to launch and the calibration will be checked throughout the mission. Spectral calibration will be accomplished using gratings to provide effective monochromatic scanned radiometric sources with $R > 2,000$. Radiometric and relative response calibrations will be performed using NIST traceable calibrated blackbodies and flood sources. The quality of the point spread function will be assessed using collimated point and extended sources. The boresight pointing shall be measured with respect to an optical alignment cube on OVIRS.

In-flight radiometric calibration will rely on three methods: an onboard array of miniature black body sources ($T \sim 700$ K) and tungsten filament sources placed at the OVIRS field-stop (and calibrated prior to launch), in-flight observations of the Earth and the Moon and absolute solar reflectance calibrations. The terrestrial and lunar calibrations will occur on the OSIRIS-REx flyby of Earth. The on-board solar reflectance calibrations will be carried out occasionally by using the spacecraft control system to point the solar calibration port at the sun. The combination of these methods will provide redundant radiometric calibration. It is expected that OVIRS will provide spectral data with at least 5% radiometric accuracy and no worse than 2% pixel-to-pixel precision. Because wedged filters are very stable, the spectral calibration is not expected to change in flight, however, the Earth and Lunar observations will also provide spectral calibrations. Spectral calibration is expected to be accurate to 0.25 of the halfwidth or better. The dark current and background flux will be measured using dark sky observations.

References: [1] Campins *et al.*, 2010, *Nature (Letters)*, **464**, 1320-1321.

[2] Rivkin and Emory, 2010, *Nature (Letters)*, **464**, 1322-1323.

[3] Reuter *et al.*, 2008, *Space Sci. Rev.*, **140**, 129-154.